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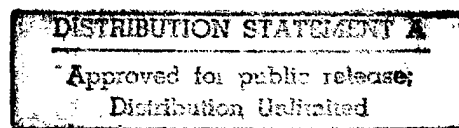TIMELINESS AND PREDICTABILITY IN
REAL-TIME DATABASE SYSTEMS

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Timeliness and Predictability in Real-Time Database Systems

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Contract Information

1. Research Objectives

The confluence of computers, communications, and databases is quickly creating a globally distributed database where many applications require real-time access to both temporally accurate and multimedia data. This is particularly true in military and intelligence applications, but these required features are needed in many commercial applications as well. Mjor applications are military command and control, avionics and weapon systems (e.g., missile guidance system), and monitoring and decision support systems. Those applications have at their core requirements for managing and analyzing massive amounts of data residing in many data repositories. Much of this data has timing attributes such as a particular satellite image being valid for no more than 5 minutes. Audio, video and images are key types of data which provide increased value to applications, but also increased challenges. Driving such systems are significant real-time requirements for managing thousands of objects and tracking them by using a global, intelligent, and responsive multimedia database system. They have the following characteristics:

(1)   transactions with timing constraints

(2)   data with temporal properties

(3)   distributed multimedia data

(4)   mixture of sensitive and unclassified data

Those characteristics lead to the following requirements:

(1)   timeliness and predictability

(2)   temporal consistency

(3)   integrated support of soft, firm, and hard deadlines

(4)   storage, retrieval and synchronization of multimedia data

(5)   security enforcement

(6) high reliability

(7) scalability of solutions

The objective of this project was to develop new database system technology for distributed real-time systems and to evaluate them in the experimental real-time database servers. Our focus has been to discover a set of design principles for building dependable and responsive database systems for time-critical applications and to develop algorithms to improve timeliness and predictability of such systems.

2. Technical Approach

Our approach to achieving the objectives stated above has been four-fold:

(1) develop a database and transaction model

(2) design scheduling algorithms to support timely, secure, and predictable execution of transactions

(3) develop paradigms and mechanisms for constructing real-time database systems

(4) evaluate the performance of the algorithms and mechanisms developed in this project using simulation as well as experimental real-time database systems.

The first two approaches (modelling and algorithm design) can be considered as basic research for setting up foundations in this area. The other two deal with actual application of the technology developed to realistic situations to evaluate their merits. Research results coming out from the second approach (practical issues) are then used to revise the models and algorithms. This kind of feedback loop approach turns out to be very effective in performing research in real-time systems area.

3. Accomplishments

3.1. Schemes for predictable transaction processing

There are many cases of hard real-time database applications in real world, such as flight control systems and missile guidance systems, and thus a flexible real-time database management system must provide mechanisms to minimize the execution time variance of a transaction, making the system's behavior predictable. We provide a framework to classify different types of transactions and to develop processing schemes for each type of transactions that can be supported in predictable real-time database systems.

3.2. New scheduling and concurrency control algorithms

The algorithms we developed based on the notion of dynamic adjustment of serialization order reduce unnecessary blocking and aborts, significantly improving the timeliness of transactions. While the original priority ceiling protocol provides a bound on transaction blocking delay and schedulability analysis, they often suffer from the problem of unnecessary blockings due to its conservative scheduling policy. The main reason for their conservatism is the implicit assumption that if a transaction conflicts with other executing transaction, it is unable to preempt the conflicting transaction. We have shown that real-time database systems could avoid unnecessary blockings using the notion of dynamic adjustment of serialization order, resulting in improved performance. Our results have been presented at several conferences, including the 13th IEEE Conference on Data Engineering held in April 1997 and IEEE Real-Time Systems Symposium, to be held in December 1998.

3.3. Integrating security with real-time requirements

In principle, any system that maintains sensitive information to be shared by multiple applications with different levels of security clearance requires multilevel security. Many of those systems also

require real-time database accesses. Especially for Navy applications, security is considered essential, in addition to real-time requirements. It has been shown that most conventional schedulers are not satisfying the security requirements. It is necessary to develop new algorithms for scheduling and concurrency control that can ensure security according to appropriate models for secure real-time databases. Our algorithms are the first ones that attempt to support both security and real-time requirements.

3.4. Multimedia data management

The essential problem of multimedia is not of providing support for individual media, rather support for "synchronizing" the otherwise autonomous data transfers across computers. The issue of real-time and synchronization mechanisms become even more challenging in distributed systems as the different media streams may arrive from different sources. Our research resulted in a systematic scheme to specify and enforce synchronization requirements in real-time systems.

3.5. Fault-tolerant scheduling algorithms

Existing fault tolerance techniques for transaction systems are inadequate in a distributed real-time system environment with respect to assuring system responsiveness - that no processing, communications, and database transaction deadlines will be missed. Since missing a transaction deadline can be catastrophic in some circumstances, the fault-tolerance of these systems must be addressed. We developed several algorithms to guarantee the hard deadlines of transactions on a multiprocessor system through statically scheduling the transactions onto different processors and using a recovery block approach to tolerate processor failures.

3.6. Replication control for critical information

As in any other systems, critical data should be replicated in real-time database systems for improved availability and fault-tolerance. However, replication involves certain overhead to maintain replicated copies in consistent states, and conventional one-copy serializability might not be desirable for its high overhead. We have developed replication management algorithms, based on a weaker correctness criterion called epsilon-serializability.

3.7. Development of experimental real-time database servers

Previous work in real-time database systems has primarily based on simulation. Our research has focused on how current real-time technology can be applied to architect an actual real-time database system. A real real-time database system must confront many practical issues which simulation studies typically ignore: race conditions, concurrency, and asynchrony. By actually constructing a real-time database server on top of several platforms including real-time kernels, we have identified many implementation issues and developed practical solutions to those problems.

Honors and Recognition

- Program Co-Chair, 3rd Workshop on Active Real-Time Database Systems, 1999

- Program Chair, Workshop on Advanced Issues of Electronic Commerce and Web-based Information Systems, 1999.

- Symosium Co-Chair, Symposium on Software Engineering, 1998.

- General Chair, 18th IEEE Real-Time Systems Symposium, 1997.

- Program Co-Chair, Fourth International Workshop on Real-Time Computing Systems and Applications, 1997.

- General Chair, 2nd International Workshop on Real-Time Database Systems, 1997.

- Program Chair, 17th IEEE Real-Time Systems Symposium, 1996.

- Program Chair, International Workshop on Real-Time Database Systems, 1996.

- Program Vice-Chair, 4th IEEE Workshop on Parallel and Distributed Real-Time Systems, 1996.

- Tutorial Chair, 3rd International Workshop on Real-Time Computing Systems and Applications, 1996.

- Steering Committee, International Conference on Real-Time Computing Systems and Applications, 1995 - Present.

- Advisory and Publicity Committee, IEEE Symposium on Object-Oriented Real-Time Distributed Computing (ISORC'98), 1998.

- Program Committee, IEEE Symposium on Security and Privacy, Oakland, 1999.

- Program Committee, International Conference on Distributed Computing Systems, 1999.

- Program Committee, International Conference for Young Computer Scientist, 1999.

- Program Committee, IEEE Symposium on Object-oriented Real-time Distributed Computing (ISORC'99), 1999

- Program Committee, IEEE Workshop on Dependable and Real-Time E-Commerce Systems (DARE'98), 1998.

- Program Committee, IEEE International Parallel Processing Symposium (IPPS'98), 1998.

- Program Committee, IEEE Real-Time Technology and Applications Symposium, 1997, 1998.

- Program Committee, ACM Workshop on Databases: Active and Real-Time (DART'96), 1996.

- Program Committee, International Conference on Information and Knowledge Management, 1996.

- Program Committee, International Workshop on Active Real-Time Database Systems (ARTDB), 1995, 1997.

- Program Committee, IEEE Workshop on Future Trends of Distributed Computing Systems, 1995.

- Program Committee, International Conference on Intelligent Information Management Systems, 1995, 1996.

- Program Committee, IEEE Workshop on Parallel and Distributed Real-Time Systems, 1995, 1996, 1997, 1998, 1999.

- Program Committee, Euromicro Workshop on Real-Time Systems, 1995, 1996.

- Program Committee, IEEE Symposium on Real-Time Systems, 1995.

- Program Committee, IEEE International Conference on Data Engineering, 1995.

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